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Effective self-synchronization in netted warfare *requires* the employment of intelligent agents. This statement is supported by a review of what intelligent agents are, what they show promise of becoming and also what they are not. A discussion follows in potential psychological and cultural challenges to implementing agent based computing in a networked military environment. The existence of such challenges has in fact been born out through recent Fleet Battle Experiments. By reviewing the employment of artificial intelligent agents in recent Fleet Battle Experiments, namely FBE INDIA and FBE JULIET, one can also begin to discern a pattern of experimental intelligent agent effectiveness in promoting self-synchronization of disparate, netted forces.

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NAVAL WAR COLLEGE
Newport, RI

# Agent Based Computing and Effective Self-Synchronization in Netted Warfare

By

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Submitted to the Faculty of the Naval War College in satisfaction of the requirements of the Winter 2003 Joint Military Operations Course.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

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There are many opinions on the feasibility of Network Centric Warfare concepts as well as the impact such concepts would have in bringing about a possible revolution in military affairs. Some proponents of NCW predict wide sweeping changes in both force structure and operations resultant from significant cultural changes in the American way of war. The characteristics of such a networked force are predicted to be a *flattening* of the traditional chain of command, an increase in *speed of command* and the *self-synchronization* of networked forces. So where then lie the indicators of the emergence of such a networked force? It is rather easy to consider network centric operations simply an improved system of communication not unlike a computer's operating system. For this same reason, it seems easy to identify recent advances in hardware such as the Navy's CEC and IT-21 systems as indicators that American military forces are well on a transformation path towards network centric warfare. However, though the beginnings of a networked force can indeed be found within such developing capabilities, other research efforts in areas such as Agent Based Computing. Artificial Intelligent Agents may provide even more significant an impact on how future military forces prepare, communicate and operate in the face of conflict at home or abroad.

Advances in various communications mediums continue to improve the quality and quantity of information available to the military commander. Therefore, there appears to be an increasing amount of merit in studying how information can be processed and disseminated throughout an organization's chain of command...no matter how flat it becomes. Artificial intelligent agents have recently begun to exhibit capabilities in facilitating both human to computer and human to human communication. Together, these communications disciplines hold significant promise in facilitating networked

forces. One can even go as far to say that effective self-synchronization in netted warfare *requires* the employment of intelligent agents. Obviously such a statement needs to be supported by a review of what intelligent agents are, what they show promise of becoming and also what they are not. As one researches more into the potential uses of intelligent agents, there appears to arise several psychological and cultural challenges to agent based computing in a networked military environment. The existence of such challenges has in fact been born out through recent Fleet Battle Experiments. However, by reviewing the employment of artificial intelligent agents in recent Fleet Battle Experiments, namely FBE INDIA and FBE JULIET, one can also begin to discern a pattern of experimental intelligent agent effectiveness in promoting self-synchronization of disparate, netted forces. What then remains to be discussed is how intelligent agents facilitate not only the mechanics of self-synchronization but the effective communication of the operational commander's intent. How is it that a future operational commander of netted military forces may then provide the essence of his/her intent across the disparate, combined, dynamic force structure predicted by Network Centric Warfare? By following this path, one can begin to see the transformational nature of agent based computing and the ability artificial agents may provide in facilitating such a self-synchronized force.

**WHAT ARE INTELLIGENT AGENTS ?**

Any discussion of Intelligent agent technology should review the concept's history as a means of approximating human intelligence. As the fields of academic and commercial computer development sought to develop a viable example of artificial intelligence, it was realized that creating even a rudimentary approximation of human intelligence was

in fact, an extremely difficult challenge. One way around the daunting task of developing artificial life/consciousness was to approximate it by breaking up complex operations into layers of increasingly small portions of focused tasks. From studies of the almost "social" interactions between such rudimentary instruction sets arose the field of intelligent agent processing and agent based computing.

Intelligent "mobile" agents can trace their lineage as a specific class of objects back to the early 1970's with the advent of the Remote Procedure Call (RPC). For the first time, RPCs allowed computer-to-computer communication by enabling one computer to call procedures of another.[1] Such rudimentary communication was based upon a pre-conceived "template" of specific information, such as procedure names, arguments and results. One can see in these beginnings an emphasis on both computer code required for each specific task as well as *state* of the data retrieved or processed by the subject RPC. The term "Mobile" or "Intelligent Agent" first became popular in the early 1990's. These terms described new approaches in computer-to-computer communication.[2] They sought to provide both code and state from one computer to the another, facilitating the traversing of both code and data object state throughout a network. This pre-conceived agreement on data content templates constituted a rudimentary set of rules or language, but was as of yet constrained to large monolithic server environments.[3] Such independently operating "chunks" of computer code began to be used to accomplish specific, pre-conceived tasks. In essence, they began to emerge as direct representatives of human operator directions while the term "agent" grew to connote a loosely organized group of small pieces of computer programming code sharing nothing more than a "familial resemblance of capabilities and functions".[4]

This idea of remotely traversing code applications has continued to become popular, due in large part to a surprising development in commercial internet applications, namely the creation of the World Wide Web (WWW). It began life at CERN, the European Laboratory for Particle Physics in Geneva, Switzerland. CERN was, and still is a meeting place for physicists often collaborating on projects from various locations all over the world. Out of this organization came the concept of enabling dislocated researchers with the ability to collaborate on projects like never before by actually *linking* the text in their documents. Such an approach facilitated cross-references from one research paper to another by quickly displaying part of another paper containing relevant text or diagrams. This effort at linking text-based documents created what is now know as the World Wide Web (WWW) by using Hypertext Markup Language (HTML).[5] As a consequence, computer-to-human interaction increased exponentially because of the Web's ability to present human operators with a ubiquitous, graphic-intensive interface that controlled essentially one command..."go there". Of course the "there" could now be any other computer connected to the internet. It's strength was in its universality and relative ease of operation.[6] If the hypertext-enabled World Wide Web is looked upon as the first in a series of advances in the digital approximation of human communication, the development of the Java programming language can be seen as the next logical step in this process.

Java technology was created as a programming tool in a small project initiated by Sun Microsystems in 1991. HTML was becoming an increasingly popular way of moving media content (text, graphics, video) throughout the internet.[7] Java's ability to move executable code along with this content soon developed into a robust programming

medium for the internet. It provided the Web with *executable content.* The Web's graphic user environment now allowed operators throughout the internet to execute code on dissimilar and dislocated computers via rudimentary, intuitive point and click operations. In essence, the Internet ceased to be a connection of static pictures with the advent of Java...it started to be able to manipulate data in means other than graphic pictures of text and images.[8]

## WHAT IS NETWORKED MILITARY AGENT BASED COMPUTING ?

As the development of the WWW and Java coding architecture continued, internet-based applications began to develop in complexity and capability.[9] Just as the ubiquity of the WWW facilitated the process of improving networked system communications, new Agent Based Computing (ABC) capabilities may have a similar transformational impact. Proponents predict a time when such value adding entities will overtake human operator input within networked systems.[10] Just as a web browser enabled graphic user interface was able to better represent human thought over text by "painting a picture" of an idea, intelligent agents are predicted to obtain the same sort of order of magnitude improvement in human communication. In order for such higher level agents to cooperate and work together to begin to make distributed decisions, or at least informed recommendations, several additional capabilities are needed.

- Agents need to easily communicate with other agents without a-priori knowledge of their existence.
- A *model for trust* must be established between the communicating agents and the information that they share.
- Cooperating agents must assess the quality of information through cross-validation techniques.
- A methodology for decision making must be devised that will learn from previous decisions and continue to improve the quality of decisions and recommendations put forth.

- Agent geographic location must be available if real-time data and sensor input is to be considered or dynamically sought out.[11]

Armed with a new field of study in agent based computing, researchers looked to develop an underlying programming language capable of enabling true agent based computing in networked environments.

The DARPA Advanced Markup Language (DAML) is one of several second generation markup languages developed recently and envisioned as a means to providing yet another "layer" of complexity while developing what has been identified as the "web after next" or "Semantic Web". The underlying concept of DAML is that having knowledge that can be dynamically applied to find an answer, rather than predefined as written procedures, is extremely powerful. It provides a basic infrastructure that allows machines to make the same sorts of simple inferences that human beings do. Currently, the markup languages used on the World Wide Web impose a significant limitation on agent based computing. To this end, the DAML program's goal is to "develop a language that allows information content to be expressed on the web in machine-readable ways."[12] The Semantic Web is yet another, more complicated logical model based on computer to computer information sharing. Its developers are working to wrap data with meaning or context, making each packet usable as a stand-alone object. Currently, machine processed data takes on the familiar forms of spreadsheets, various other types of office documents, or raw sensor data. Such information is only useful when compared to other data or presented for a human operator to evaluate based on desired parameters. The goal of agent based processing is to place such a tablet of parameters within the agent to facilitate autonomous evaluation of data. Success of such a model lies in its population of agent-enabled data. The Semantic Web concept transforms the internet/intranet

structure into an agent-friendly environment. Much like human operators using hypertext links while evaluating information displayed in static text documents, semantic web agents are envisioned as capable of either independent direct data processing, or using semantic hyperlinks to autonomously seek out definitions of key terms and rules to allow them to reason logically.

> "The challenge of the Semantic Web, therefore is to provide a language that expresses both data and rules for reasoning about the data and that allows rules from any existing knowledge-representation system to be exported onto the Web"[13]

Semantic markup languages differ from earlier versions of web based computing languages by developing separate packets of data attached with three distinct descriptors, which correspond roughly to the subject, verb and object of an elementary sentence.[14] Such a construct allows for multiple definitions of the same word or phrase, based on context, which in turn fosters an even more exciting applications such as speech enabled agent systems.

The advent of a semantic web would also quickly be seen as a key technological innovation, capable of handling the complexity of modern warfare. Such a netted environment works very nicely into most network centric scenarios of distributed computational entities acting on behalf of, mediating, or supporting the actions of human users and autonomously carrying out tasks. Such agents would improve information and decision management capabilities. DARPA's Agent Based Computing (ABC) suite of programs is aimed at providing the building blocks for understanding and implementing intelligent software agents. Currently, these efforts revolve around three initiatives, namely the previously discussed DAML program, the Control of Agent-Based Systems (CoABS) program and the Taskable Agent Software Kit (TASK) program.

## WHAT IS THE CoABS GRID ?

The CoABS program is best viewed as a test bed of sorts for emerging concepts in the field of agent based computing. It consists of three elements - the agent grid, agent interoperability standards and a focus on scalability the scaling of agent control. Over the past six years, CoABS has developed into a real-world system capable of integration with other software agents and entities such as servers, databases, legacy systems and sensors. In short, it works and has been deployed along with the TASK Toolkit in the last two Fleet Battle Experiments through an alliance with the Naval Warfare Development Command as a test bed for network processing initiatives. CoABS became attractive as a means of testing network-enabled technologies because of its ability to assemble disparate information systems into a coherent interoperating whole without redesigning or reimplementing (i.e. reprogramming or coding) the systems into a single common architecture. The system achieves this by constructing an information environment where disparate systems are accessible to each other and their users, resulting in an intelligent distributed information system.[15] The technology underlying the CoAbs grid was developed by Sun Microsystems, appropriately enough the original designers of the Java programming language upon which the system protocols are based. Underlying CoABS is an architecture for the construction of systems from objects and networks. It's strength lies in its ability to allow different types of programs and agents to use services in a single network. The client (or agent) is, in effect, taught by the network how to talk to it. The architecture of the network is essentially based on a "plug and play" concept...bring what you have and we will plug it into the existing network. Current "legacy" systems can be brought to the grid through software "wrappers" and

service descriptions, allowing their functionality to be tapped without major recoding.[16] Such an approach has the potential to be invaluable when applied to military command and control distributed network processing.

The networked military environment is more dynamic than ever before, characterized by quickly changing operations, hardware and software modifications and multiple connections, all under the umbrella of varying bandwidth availability. "Inflexible stove-piped legacy systems that were never meant to be integrated are, nevertheless, of vital importance to military planning and operations."[17] Even before one throws in the idea of cognitive loading, or how much an operator is capable at processing into useable information, it is easy to see how military personnel can be overwhelmed by the increased amount of available data. Like never before, the modern battlefield presents a danger of human operator information overload if adequate tools to filter and correlate the data are not provided. A goal of CoABS is to work within this murky environment of both man and machine. Nicholas Negroponte, Director of MIT's Media Lab, provided an excellent example of a traditional military command and control interface design:

> " I remember visiting an admiral in the mid-1970s who had one of the most advanced command-and -control systems. He would bark orders to a junior seaman, who would dutifully type in the proper commands. So, in this sense, the system had a terrific interface: it had speech-recognition facilities, and patience as well. The admiral could walk around the room, talk, and gesture. He could be himself..." [18]

Though a bit cynical in his portayal of circa 1970s era naval command, it does point out an inherent feature of all successful command and control systems...they must let operational leaders be themselves. In this case a human operator has been inserted into the organization in an effort to ensure the most dynamic interface available. Though effective, such an approach is both inefficient and manpower intensive. However, regardless of C2 organization structure, the operational commander must still be allowed

to "be himself". Negroponte also proposes what a properly developed agent based network interface may some day look like:

> "The best metaphor I can conceive of for a human-computer interface is that of a well trained butler. The "agent" answers the phone, recognizes the callers, disturbs you when appropriate, and may even tell a white lie on your behalf. The same agent is well trained in timing...and respectful of idiosyncrasies. People who know the butler enjoy considerable advantage over a total stranger. That is just fine."[19]

If it is true that someday all networked data will reside in a "knowledge soup" where agents assemble and present small bits of information from a variety of data sources on the fly, then Negroponte's "butler" most surely applies.

## FLEET BATTLE EXPERIMENTATION

Originally released in 1999, the CoABS Grid has been developed specifically as a means of testing new approaches to networked military command and control structures. Its inherently dynamic nature has been applied to several recent Fleet Battle Experiments to examine its ability to maintain adaptive and robust command and control functions. CoABS developers aim to provide a simple means for combatants to dynamically create new software agents while the battlespace evolves...in essence, letting combatants "be themselves".

The CoABS Grid was first used in Fleet Battle Experiment INDIA with successful results. It was used to test two high level hypotheses: (1) That "an agent based computing infrastructure can, in an environment containing large numbers heterogeneous sensors and systems, provide access to, and delivery of all relevant information where and when it is needed" and (2) that "an agent based computing approach is superior to traditional hard-coded techniques".[20] Results of FY01 testing during FBE INDIA revealed: (1) "Interoperability can be achieved cheaper, faster, more efficiently with

service-based middleware than by traditional hard-coded means." (2) Dynamic reconfigurability is enabled by an agent based computing infrastructure, reducing time to achieve full operability after configuration changes. (3) Agent-base computing can be implemented in Navy networks without an adverse impact on network security, and (4) A mobile-agents-based implementation can lead to significant bandwidth conservation.[21] Most of the FY01 CoABS and agent based computing testing focused on lower level "nuts and bolts" hardware implementation and savings. With the success of FY01 testing, CoABS was again implemented in Fleet Battle Experiment JULIET. Efforts and test initiatives were expanded in a number of areas. Specifically, more sensors were added to test the grid's dynamic hardware management capabilities while the scope of the grid was enlarged and the beginnings of testing on "top layer" fusion and C2 products were added. Finally, through a series of CoAX (CoABS Coalition) Experiments, the ramifications of coalition partners were addressed in an agent-based computing environment. FY02 agent based experiments were focused on higher level functions testing the following hypotheses: (1) Can agent based computing (ABC) enhance delivery of actionable and confirmable information to the warfighter ? (2) Can ABC expedite the retrieval of data and information from large numbers of multi-phenomena sensors ? (3) Can ABC facilitate reduced manning ?[22] Testing revealed significant progress towards implementing the visions and promises on Network Centric Operations and FORCEnet capabilities.

**NETWORK CENTRIC OPERATIONS**

Network Centric Operations is a subset of the Network Centric Warfare (NCW) concept, actually an interconnected pattern of concepts, used as a set of guidelines against which research and development efforts can be measured. Though NCW is often viewed

as a physical program of technologies to be developed under a set timeline and one project heading, it may be better understood simply as a *theory of communication* and as such is rooted in the concepts of agent based computing initiatives. Because its beginnings can already be seen in recent advances in nascent military information technology systems, it is easy to envision a Network Centric Warfare Operating System. However, a more accurate approach to defining the Network Centric Warfare concept may be obtained by viewing it as a process of the *"co-evolution of technology with operational concepts, doctrine and organization..."*[23] Given such a view, there has emerged a logical model of network centric forces. This theory of interconnected information structures proposes three types of grids; a high performance information grid, sensor grids, and engagement grids.[24] Proponents of the NCW concept go on to suggest that the beginnings of such grids are either in place or are under development. In fact, the CoABS Grid has been described as a test bed for concepts to be established in the architectures of all three NCW "grids". Such initiatives are examples of a shift from traditional *platform centric forces* to network-enabled or *network centric forces* which enable the sharing of information to obtain an improved image of the battlespace.[25] Further evidence of grid development and the exchange of physical sensor data is demonstrated through the Navy's Expeditionary Pervasive Sensing (EPS) Experimentation program, of which CoABS is a part.

How then does the NCW model of synchronization propose a military force gain advantage over one's adversary? It boasts of competitive advantages gained through the efficient connection of traditionally separated force functions. At its foundations, NCW concepts describe ways in which *information-enabled* organizations can gain competitive

advantages by both "leveraging available information and fostering the ability to make better decisions."[26] As information is gained on one's adversary, it must be processed and communicated throughout an information-enabled organization. The familiar term *"stovepipe communication paths"* describes how a non-information enabled organization's communications architecture may develop information flow biases. In such instances, only various discrete departments or sections of the organization are enabled with required information. These formally established sub-sections within the organization are created only to process information in a standard way and thus may only receive "part of the picture", enough to accomplish assigned tasks and no more. As agent based computing initiatives continue to allude to new means for organizations to share information across functional areas, one can see how Network Centric Warfare concepts may be able to embrace the development of virtual organizations that can be tailored by modifying formerly rigid information paths to suit current organizational goals. These competitive advantages are borne out through the metrics of *speed of command, quality of information* and *self-synchronization* of networked forces.[27] All three terms have a significant impact on agent based computing development.

The changing nature of war, driven by post-Cold War political and economic realities has expanded the arena in which future American policy objectives will be pursued. Our nation's military will be required to adapt to this new environment.[28] The current trends of military actions other than war (MOOTW), ideologically driven asymmetric warfare and the muddled nature of tasks associated with identifying combatants all point to an evolving *battlespace* and a requirement to transform American military forces.[29] The proponents of NCW predict that much like the business world, as

information is communicated across traditional functional areas, subordinate levels within the chain of command will begin to understand more about how various functions "fit into" the overall plan, fostering further information sharing and culminating in a mutual "shared awareness" of the battlespace. The virtual distance between the highest and lowest echelons in the chain of command will shorten as the tasks of processing some types of information are automated by agents, eliminating the need for a significant number of the traditional organization's "middle-men".[30] This improvement in the overall efficiency of the organization's communications processes has been described as a "flattening" of the traditional hierarchal C2 organization. As more participants are added to the collaborative networked organization, an increased quality of information is produced, leading to a synergy of goals.[31] This *self-synchronization* of military forces minimizes gaps in information continuity throughout the organization. Therefore, it improves both speed and quality of information flow, both essential parts of *speed of command*. Network Centric Warfare therefore describes an iterative process of communication of information that continues to improve upon itself, taking advantage of a larger group of participants in the organization's overall goal.

## CULTURAL CHALLENGES

Some have warned that if developed incorrectly, Network Centric Warfare encourages the diminishing role of the operational commander as a mere participant in a series of networked entities.[32] Through a better understanding of what the Network Centric Warfare concept does propose, one can see the fundamental role the operational commander will always be required to play in a networked force. Though it proposes significant modifications to the traditional form of the hierarchal military command and

control structure, it does so with an eye for this essence of human interaction. Commander's Intent may provide the context which then encourages the self-synchronization of forces.

How is it that the essence of an abstract human thought or an impression on the state of a battlespace can be communicated via digital means? Furthermore, how is such information communicated via any means, face to face or digital? The information technology required to enable a networked force, though formidable, is not the most significant challenge facing proponents of NCW. One can assume advances in technologies such as CEC, the Joint Technical Architecture and Agent Based Processing will continue to improve the physical means of communication between the three NCW grids. Some have proposed a new description of the command by influence version of commander's intent as an image or mental model instead of traditional voice or text message.[33] This idea predicts advances in "synthetic environment technology" will allow for the transmission of the "intent of the commander" as a "symbolic representation of the mental image" and thus opens the discussion of the digital representation of commander's intent. Agent based computing initiatives may provide the ability for future networked operational commanders to continuously distribute a commander's intent modified to constantly fit the evolution of the battlespace.

The traditional operational commander's tasks of strategy development, force assessment and human employment can now be viewed from within a network centric structure. Applied to a self-synchronizing, collaborative organization, the traditional planning process becomes an iterative planning and adaptation process whereby autonomous agents may facilitate the significant amount of "crosstalk" required by self-

synchronized forces. In such an organization, the operational commander would become a manager of the network, guiding the flow of information by means of a robust, multimedia image of command intent. Within this environment, a successful operational commander would have to embrace a more collaborative decision making process.

As emphasis is shifted from a sequential planning process to a more dynamic series of alternatives, a new form of commander's intent must be brought forth to provide structure and assist in the synchronization of networked forces. This new structure should be able to efficiently deal with complex decisions by providing a set of options, criteria for choosing among options and a set of rules by which these options are integrated into an organization's shared awareness of the battlespace. The technology of agent based computing has promise in providing such a structure, able to support the care tasks associated with commander's intent. Self-synchronization is a byproduct of this detailed collaborative planning process and shared situational awareness. The commander's intent is promulgated in the form of a plan for others to follow. As the plan is disseminated via intelligent agents, synchronized forces are engaged in developing the "image" that will enable them to make further decisions based on what is to be accomplished, what assets are to be used, schedules, boundaries and contingencies. The goal of such an architecture is that planning will become more synchronized across all echelons of the chain of command and across all functional entities within the networked architecture. The networked military commander will be required to delegate responsibilities traditionally performed by collocated staff to dislocated, networked commands. Agent based computing initiatives can facilitate such a shift to a "flattened" version of the C2 structure by influencing an increased number of autonomous intelligent agents able to

communicate freely throughout the networked force. The evolution of intelligent agents into *battlespace entities* with increasingly complex layers of code approximating specific limited traits of artificial intelligence will be essential in order to continuously organize the *most effective* force available for a given situation and present such a dynamic organization to the networked commander on a recurring basis.

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